

HYDROLOGY APPENDIX

1 HYDROLOGIC PROCESSES

Hydrology, in the context of stream habitat restoration involves study of the quantity and timing of flow throughout the stream system. Related areas of study include the delivery of water to the stream system, channel/floodplain interactions, groundwater/surface water interactions, and fluvial geomorphology (see Appendix F, Fluvial Geomorphology). The magnitude and duration of flood flows - generated by climatic events and mediated by the watershed - interacting with sediment, riparian and floodplain vegetation, and human developments provide the energy that shapes and maintains the channel in its characteristic geometry. Developing an understanding of the magnitude and duration of the flow characteristics (both high- and low-flow) at a project site is a key element in planning stream habitat restoration and streambank protection.

Hydrologic processes can be studied on a range of scales from the watershed to a site-specific project location. Watershed hydrology involves the study of the supply of water and movement of water through the landscape and the factors influencing that movement: climate, geology, geomorphology, soils, vegetation, and land use effects. Human impacts, such as infrastructure, dams, flood control, and irrigation practices also influence the hydrologic regime.

1.1 *Stream Flow Characteristics*

1.1.1 *Stream Flow Hydrographs (Discharge vs. Time)*

One of the tools used to evaluate stream flow at a given location on a stream is a *hydrograph*. This is a graph that tracks the rate of runoff (discharge plotted against time) and expresses the unique character of the associated watershed. V. T. Chow¹ describes the hydrograph as “an integral expression of the physiographic and climatic characteristics that govern the relations between rainfall and runoff of a particular drainage basin”, at a specific time in history which includes landuse and other watershed characteristics. Discharge is expressed in the hydrograph as volume per unit time; that is, cubic feet per second (cfs) or cubic meters per second (cms). Discharge is plotted on the vertical (ordinate) axis, and time is plotted on the horizontal (abscissa) axis.

Annual hydrographs and storm hydrographs are the two most important types of hydrographs. Annual hydrographs plot stream flow for an entire water year. The total volume of flow tracked on an annual hydrograph is the *basin yield*. An example of an annual hydrograph is shown in

Placeholder - Figure 1

Figure Hydrology-1. Annual hydrograph of a storm-driven stream in western Washington - use figure from ISPG Hydrology appendix

A storm hydrograph plots discharge during a single storm event whose time units may be in days or hours. Figure Hydrology-2 shows four components of a hydrograph during a storm. The flow volume represented in the curve segment AB is usually called “base flow” – the low flow that occurs between periods of precipitation or snowmelt. A stream’s base flow comes from groundwater that seeps from aquifers and surface soils. Segment BC on the storm hydrograph is the “rising limb,” where direct runoff begins at point B, and flow volume peaks at point C. Flow rates then decline, as represented by Segment CD, ending at D. Segment DE represents the return to a normal base-flow discharge. The “lag to peak” is the time difference from the moment of highest rainfall intensity to the peak runoff rate and is largely dependent on pre-existing moisture conditions, soil-infiltration rates, and drainage area.

Figure Hydrology-2. Storm hydrograph.²
Placeholder - Figure from ISPG Hydrology appendix

1.1.1.1 Storm-Driven Systems

(Comment: This paragraph is poorly organized. Spring-fed streams are a relatively small component of the stream system & shouldn't 'lead off'. I suggest that it be rewritten to discuss ephemeral, intermittent, and perennial stream i.e., moving down through the watershed.)

A typical storm hydrograph from a perennial stream in Washington is shown in Figure Hydrology-3. A stream that originates from a spring or is fed primarily from groundwater will have a very smooth hydrograph curve, indicative of relatively constant base flow. Discharge may gradually rise and fall in relation to seasonal precipitation patterns and their influence on the groundwater table. The water table recharges or rises in elevation during wet periods, rising in elevation, and falls during drier months. In contrast to perennial streams, ephemeral streams have extended dry periods of no surface flow in the channel, followed by intervals of abrupt or “flashy” discharge caused by storm events. In this case, rainfall usually becomes direct runoff and reaches the channel as overland flow. Overland flow is a thin layer of water that spreads over a wide surface or slope before it is concentrated or confined to a channel. Overland flow occurs when rainfall intensity of a given storm exceeds the soil-infiltration rate of the basin.

Figure Hydrology-3. Storm hydrograph of a perennial stream in Western Washington. Placeholder - Use ISPG figure.

1.1.1.2 Snowmelt-Driven Systems

In regions where the majority of annual precipitation comes in the form of snow, runoff from snowmelt during spring and early summer comprises the majority of basin yield. A snowmelt-driven system usually creates a smoother curve on a hydrograph (Figure Hydrology-4) than storm-driven streams (e.g., Figure Hydrology-1) because a snow pack usually supplies a steady rate of flow. However, a rain-on-snow event, where rain and snowmelt simultaneously contribute to runoff, often produces dramatic spikes in the hydrograph that may correspond to flooding. These events occur as a result of the ambient air temperature warming, which causes precipitation to fall as rain rather than snow, with the

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warm air and wind also contributing to the melting of the snowpack. The contribution of rain and snowmelt can also coincide with saturated soil conditions, where the ground can no longer absorb or store water, resulting in the direct discharge of overland flow to surface waters. Rain-on-snow events are frequent in the mountainous regions of western Washington and are a common cause of extreme flow conditions and flood events.

Streams influenced by glacier melt may exhibit a unique hydrograph that peaks in summer months, and exhibits daily fluctuations influenced by temperature and sun in the headwaters.

(Comment: How about creating a section for the Transient Snow Zone?)

Figure Hydrology-4. Storm hydrograph of a snowfall-driven stream in eastern Washington.
Placeholder – figure from ISPG

1.1.2 *Gaining and Losing Stream Reaches*

Streams can be classified as either “losing” or “gaining” depending upon whether surface flow is lost to or gained from groundwater. Where the surrounding water table is elevated above the water surface of the stream, the stream ‘gains’ flow. Where the water table is below the water surface of the stream, the stream ‘loses’ flow, unless the bed is sealed. Sealed beds are common where fine-grained sediment is readily available and disturbance of bed substrate is infrequent. This may occur in glacier-melt systems where glacial flour contributes fine sediments.

Typically, a drainage system’s base-flow volume increases in the downstream direction; this may be defined as a *gaining* stream reach and is common throughout western Washington. A *losing* stream reach occurs where base-flow volume decreases in the downstream direction. Losing stream reaches are most common in arid climates where water tables often are relatively deep below the ground surface. Flow diversions (as discussed in the following sections) may affect the water table, lowering it below the point of diversion and possibly increasing it in the vicinity of the delivery system and application area. This can affect the timing, distribution, and net gain or loss of groundwater/surface water interactions. . Many streams have losing reaches alternating with gaining reaches, as the depth to water table fluctuates due to subsurface geology, seasonal cycles, and/or surface- and groundwater withdrawal. Thus, the exchange of surface water and groundwater is a dynamic system and varies both spatially and temporally. Losing reaches are often noticeably sparse in riparian vegetation, due to the inaccessibility of the water table during the growing season. Losing reaches should be identified prior to planning stream habitat restoration or streambank protection projects so that the natural potential of the site can be realistically assessed.

1.1.3 *Hyporheic Flow*

The exchange of groundwater and surface water takes place within the hyporheic zone, which can be defined as “the saturated interstitial areas beneath the stream bed and into stream banks that contain

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some proportion of channel water or that have been altered by channel water infiltration”³ (White 1993). This zone is dynamic in both time and space and may fluctuate daily, seasonally, or annually depending on variations in precipitation and other variables that influence hydrology. Despite the challenges inherent in studying and identifying hyporheic function, or limitations to hyporheic function, acknowledgement of the importance of this process is essential to holistic approaches to habitat restoration. Surface water/groundwater interactions within the hyporheic zone provide ecologically vital physical, chemical, and biological. Bolton and Shellburg (2000)⁴ list the following habitat functions provided by the hyporheic zone:

- Retention and storage of water
- Regulation of stream temperature
- Physical habitat for hyporheic organisms including: invertebrates, spawning incubation, and fishes
- Refugia for hyporheic organisms
- Retention and transformation of nutrients
- Control of ecosystem metabolism
- Promotion of aquatic and riparian habitat diversity

1.2 Regulated Flow Regimes

There are few major stream drainages that are still undeveloped. Most streams are affected by some form of man-made flow regulation that impounds, diverts, augments and/or modifies their natural hydrologic regime. When examining a historic hydrologic record in a regulated stream, it is often necessary to bracket the data; that is, separate the data based on the chronology of development. For example, separating differences in the flow regime from pre-dam to post-dam hydrologic conditions is necessary to plan and anticipate future conditions. In an urban area, the different flow regimes existing before and after development (e.g., accounting for the influence of impervious ground surface) should also be evaluated.

1.2.1 Reservoirs, Dams, and Levees

Dams often serve multiple purposes of generating hydroelectric power, providing storage for agricultural diversions, or for flood control. Regardless of the purpose of the dam, the effects of dams on the hydrology of a system can be dramatic. Generally, the ability of a dam to store water lowers the magnitude of downstream peak flows. However, the rate at which the dam releases its stored water may also *increase* a river's low. Flows released to generate power through turbines often create a sudden increase in discharge downstream, often referred to as “ramping up.” Once the demand for power is met, flows are rapidly reduced. This cyclic rise and fall of flow can affect the morphology by altering erosional and depositional processes and sediment transport downstream. Hydrologic impacts of flow control affect the entire river ecosystem, changing the temperature regime, aquatic food web, physical habitat, erosional and depositional processes and riparian plant communities.

Other flood-control practices that affect hydrology are stream channelization and the construction of

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levees. Channelization may reduce the frequency and duration of overbank flooding through the channelized reach by increasing flow velocities (as a result of increased slope). Areas downstream of the channelized reach may experience increased frequency of overbank flooding, however, due to the more rapid delivery of flow from channelized reaches. Levees may also increase the frequency of overbank flows downstream by reducing flood flow storage in the floodplain. The faster the flood flow moves through the channel (due to either channelization or levees), the less likely the channel is to flood at a given location, and the more severe flooding becomes downstream.

1.2.2 Diversions

1.2.2.1 Seasonal Irrigation Practices

Agricultural diversions reduce stream flow and aquatic habitat throughout the irrigation season. Peak water demand normally overlaps the summer base flow period, often creating conflicts between aquatic resource and agricultural concerns. In the extreme, creeks are completely dewatered during summer. Water temperature problems are exacerbated by reduced flows, especially where groundwater pumping and loss of stream/floodplain interactions have eliminated groundwater/surface water interactions.

1.2.2.2 Water Supply

Another diversion practice involves industrial and municipal water supplies. These types of diversions are used throughout the year and do not result in the seasonal flux that is typical of irrigation diversions. However, during a drought or in the driest months of the year, diversions (in total) may completely dewater a system if in-stream flow requirements are not identified and maintained.

1.3 Urban Hydrology

Urbanization of a watershed has a profound impact on stream hydrology. Increased impervious surfaces are a common cause of increased peak flows. Examples of impervious surfaces include paved streets and parking lots, and roofs. Impervious surfaces decrease soil infiltration rates to zero (see Figure Hydrology-5). As runoff volumes in urban channels increase (because water is no longer infiltrating the soil), the duration of high flows decrease (because groundwater is no longer the major contributor to the flow). Also, urban development causes a decrease in lag time between rainfall and runoff by increasing the hydraulic efficiency of the drainage system (water can reach the channel more swiftly when it travels over smooth, hard surfaces). Artificial channels, curbs, gutters and storm sewers increase the magnitude of flood peaks by creating smoother conveyance and decreased storage in the channel and surrounding drainage area.² Increased peak-flows, result in more hydraulic force acting on a stream channel. On the other hand, when storm flows are captured in detention facilities and gradually released, in some instances, storm-flow duration increases from that of undeveloped. Storm flows may also be captured in one watershed and released in another nearby watershed, thereby changing watershed boundaries and resultant hydrographs.

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Figure Hydrology-5 Urban hydrograph⁵.

The incorporation of storm-water detention basins and storm sewers greatly complicates hydrologic analysis. Urban hydrologic modeling is complex and time consuming, but essential to design of aquatic habitat and streambank-protection projects. Gage data and traditional models discussed in the following sections are useful, but inadequate to do the whole job. Urban hydrologic systems often require data collection and modeling that is specific to the urban catchment under consideration. The following provides a general outline for hydrologic analysis of urban settings when designing a habitat or streambank-protection project:

- Determine whether the channel has responded to altered hydrology (refer to Appendix *Fluvial Geomorphology*),
- Consider potential changes in watershed boundaries due to storm-sewer configurations,
- Evaluate flow records with respect to level of urbanization, and
- Consider future urbanization trends and possible hydrologic responses.

2 HYDROLOGIC ANALYSIS

2.1 Historic and Current Hydrologic Data

2.1.1 USGS Gaging Stations

The United States Geological Survey provides the most complete and widely used data for hydrologic analyses. USGS gaging stations are found on almost all major drainage systems and are invaluable sources of data and information. The data for most gaging stations are reported as mean daily flow. In some cases, the instantaneous maximum and minimum daily flow values are also reported. Many gaging stations are no longer in operation, so historic data may often be the only hydrologic data available for a particular river system.

Information on where to find hydrologic Data/historic data for all USGS gaging stations as well as recent and current (real-time) hydrologic conditions for many gaging stations is available from the USGS website. The local or regional USGS office may be able to help obtain more recent data and qualifications of historic data. Other sources of potential hydrologic data are state and local agencies and federal agencies (e.g., U.S. Forest Service, Bureau of Land Management and Bureau of Reclamation).

2.1.1.1 Statistical and Probability Analysis of Hydrologic Data

Interpreting a past record of hydrologic events to determine future probabilities of occurrence is known as “frequency analysis” and is often the basis for planning and designing aquatic habitat and streambank protection projects. The method of analysis depends upon the data that is available. If the project site is located within a reach where a record of floods exists, the data can be used directly. In the absence

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of a flood record, other data from neighboring stations can be regionalized and applied to the prediction of floods at the ungaged site.⁶

The most commonly applied hydrologic statistics for habitat and streambank-protection design are the following:

- *Return Intervals* – the average interval between events equaling or exceeding a given magnitude, and
- *Exceedence Probabilities* – the chance that the annual maximum event of any year will equal or exceed some given value. Probabilities are the inverse values of return intervals.
- *Flow duration* – the percentage of time that a given flow is equaled or exceeded.

The references listed at the end of this appendix provide a more detailed and comprehensive methodology for statistical analyses of hydrologic data.

2.1.2 Flood-Frequency Analysis

Design criteria for habitat and streambank-protection projects will include hydrologic events (often referred to as an x -year flood, such as a 100-year flood) as descriptors. The preferred method (Federal standard) for determining flood frequency is the Log Pearson Type 3 analysis. A complete discussion and reference for performing Log Pearson Type 3 analyses is available in Water Resources Bulletin 17B.

Determination of the hydrologic regime must be completed prior to any design. Typically, other design criteria for mitigation and habitat design projects will depend upon the hydrologic values derived.

The next section provides a summary of hydrologic characteristics that must be identified as part of the design process for habitat restoration or streambank-protection. If any of these characteristics don't apply or are impossible to determine, given available data, it is important to demonstrate why, and then describe how the design criteria can be met without an understanding of these characteristics.

2.1.3 Estimating Hydrology at Gaged Stream Sites

The hydrologic statistics described in this section are typically derived from historic stream gage data. One must decide if the period of record is long enough to be statistically significant or what portion, if any, of the period of record is relevant. Gage data usually include mean daily flows. If the project site is in an urbanized or suburbanized basin, or on a small (i.e., first- or second-order) stream, it is better to use instantaneous peak flows rather than mean daily flows for deriving statistics. Likewise, only a short period of record is usually relevant in an urban environment because rapid development and changing hydrologic conditions tends to make historic data obsolete. Therefore, segmenting the data set to best represent existing or future conditions may be necessary, but it may also leave only a small amount of relevant data to work with.

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One-, two-, five-, 10-, 20-, 50- and 100-year flows. These flows are the annual maximum flows that have an average return interval of the stated number of years. Their probability of occurrence in every year is the inverse of the return interval. The *annual maximum series* consists of all maximum annual flood events. For all statistics less than the 10-year event, a *partial-duration series* should be employed, which uses all flood peaks greater than some arbitrary base magnitude, usually the smallest number of the annual-maximum series. The recurrence interval derived from a partial-duration series is the average frequency of occurrence between floods of a given size irrespective of their relation to the year, or it is the average time between flows that equal or exceed a given base discharge.⁷ For all statistics greater than the 10-year event, use either a partial-duration series or an annual, maximum-data series.

Flow Duration

In addition to the statistics above, one should consider whether or not the project requires an analysis of flow duration. Flow duration refers to the percentage of time that a given flow is exceeded during a given time period. Flow-duration statistics must be tailored to the specific nature of the project proposed. Generally, any project that includes stated objectives of habitat components designed to sustain a specified life stage should be based on flow-duration statistics. However, flow-duration statistics can only be generated if gage data are available. Additionally, flow-duration statistics should be based on data specific to the season for which the design is relevant. Note that USGS-derived flow-duration statistics are not applicable, as they are generally not seasonally specific. For example, if a design objective is to sustain sufficient flows for spawning, duration statistics should be based only on those daily-flow data collected during the time of spawning. Hydrologic analysis must include a discussion of what flow-duration data are relevant, whether or not there are sufficient data to derive flow-duration statistics and how they will be derived and applied. For further information regarding derivation of flow-duration statistics, refer to Dunne and Leopold's book, Water in Environmental Planning.³

Stage-Discharge Relation (Rating Curves)

In hydrology, the term, "stage" refers to the elevation of the water surface above some arbitrary datum. Stage is recorded at gaging stations by measuring water-surface elevations. Stage-discharge relationships are records of stage as a function of flow.⁴ The stage-discharge graph is called a "rating curve." A rating curve can be helpful in establishing design parameters for a project, such as where and how a given discharge will correspond with a physical attribute of the channel (e.g., an inset, low-flow channel or the bankfull stage).

Estimating Hydrology at Ungaged Sites

Where gage data are determined to be absent, insufficient or of questionable reliability, estimating hydrology can be derived through modeling or analysis of precipitation events using data from other stations in the region. It is important to understand that flow resulting from a given precipitation event does not translate to a stream flow of the same probability. For example, the flow resulting from a 10-

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year, 24-hour rainstorm is not the same as a 10-year flow event. Be certain that *stream-flow* statistics are provided, not precipitation data. If alternative statistics are presented, justification for their use should be provided. In either case a standard deviation should be added for statistical error.

Regional analysis for ungaged sites works only if flood-frequency characteristics of the various basins having flood records can be correlated with meteorological or physiographic parameters. If these parameters are available, floods at ungaged sites can be estimated from the physical geography of the basin. This method assumes that, for a large region, homogeneous meteorological and physiographic conditions exist, and individual basins in the region have flood-frequency curves of approximately the same slope.⁴ If appropriate, regional regression equations can be derived and are often available from the USGS. Common regression variables include:

- Basin area,
- Mean basin elevation,
- Annual rainfall, and
- Mean channel width.

2.2 Single-Event Runoff Models

The temporal and spatial variations of precipitation, hydrologic abstractions and runoff form the basis of simulation models. Single-event runoff models are stormwater models, designed to evaluate direct runoff by simulating individual rainfall events with an emphasis on infiltration rates, and time steps (time of concentration, time of travel and occurrence of rainfall intensity). These models simulate flood events with no provisions for pre-existing soil-moisture conditions. They are designed to either create or use hydrographs. These models are best used for determining peak discharge from a synthetic or derived storm event. These models were originally created for small, urbanized watersheds, where basin characteristics are uniform so basic assumptions can be made for permeability, time of travel, time of concentration, routing, and storage, and should not be used for stream restoration projects.

Examples of these models include:

- the US Army Corps of Engineers, HEC-1 model⁸,
- the US Natural Resources Soil Conservation Service, Project Formulation-Hydrology model (Technical Release No. 20)⁹; and
- the US Natural Resources Soil Conservation Service, Urban Hydrology for Small Watersheds (Technical Release No. 55)

HEC-1 develops a series of interconnected sub-basins with hydrologic and hydraulic components. Components may be surface runoff, a stream channel or a reservoir. HEC-1 calculates discharge only, but stage can be indirectly calculated from additional user input. The result of the model is a computation of stream-flow hydrographs at the targeted location within the watershed.

NRCS Technical Release 20 (TR-20) provides the user with a hydrologic analysis of flood events. TR-

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20 was formulated to develop runoff hydrographs; route hydrographs through both channel reaches and reservoirs, and combine or separate hydrographs at confluences. This model is best applied to watersheds where peak flows are generated by thunderstorms or other high-intensity, short-duration storms.

NRCS Technical Release 55 (TR-55) presents simplified procedures to calculate storm runoff volume, peak rate of discharge, hydrographs, and storage volumes required for floodwater reservoirs. These procedures are applicable in small watersheds, especially urbanizing watersheds, in the United States. The primary functions of the program are for peak runoff computations using the Graphical Peak Discharge Method, the Tabular Peak Discharge Method and Temporary Storage.

2.3 Hydraulic Flow Models

Other more advanced models can determine water surface profiles as well as varied flow, sub-surface flow, and storage requirements for both water quality and water quantity. When the model is solving the equations, it takes the givens at one position (a known boundary condition) and solves for the head and velocity at another position. One-dimensional numerical surface water models are based on the conservation of continuity and momentum and they assume cross-section averaged flow, in steady state conditions, and a flat water surface elevation across each cross section. Again, these models simulate events with no provisions for pre-existing soil-moisture conditions without advanced modeling experience.

Examples of these models include:

1. US Army Corps of Engineers, River Analysis System Model, (HEC-RAS). HEC-RAS analyzes networks of natural and man-made channels and computes water surface profiles for subcritical or supercritical flow based on steady or unsteady one-dimensional flow hydraulics. The system can handle a full network of channels, a dendritic system, or a single river reach with an analysis of all types of hydraulic structures.
2. Federal Highway Administration (FHWA), Water Surface Profile Model (WSPRO). WSPRO computes water surface profiles for subcritical, critical, or supercritical flow as long as the flow can be reasonably classified as one-dimensional, gradually-varied, and steady flow. It can be used to analyze open-channel flow, flow through bridges (single or multiple openings), embankment overflow, floodway analysis, and bridge scour.

2.4 Continuous-Flow Simulation Models

Continuous flow simulation models account for changes in a hydrograph over time resulting from changing flow inputs. Stream-flow simulation models are based on continuous stream flow within a watershed and its channels. These can be extremely valuable for estimating discharges resulting from a series of precipitation events, particularly in urban environments, and for determining the frequency and probability of discharge values resulting from precipitation events.

1. Environmental Protection Agency's Storm Water Management Model (SWMM)¹⁰. SWMM is a large, complex model capable of modeling the movement of precipitation and pollutants from the ground surface through pipe and channel networks, storage treatment units, and finally to receiving waters. Both single event and continuous simulation can be performed on catchments having storm sewers and natural drainage, for prediction of flows, stages and pollutant concentrations.
2. The Hydrological Simulation Program – FORTRAN (HSPF) is a comprehensive package for the simulation of watershed hydrology and water quality. HSPF uses watershed-scale models for a basin-scale analysis on one-dimensional stream channels. The Stanford Watershed Model serves as the basis for HSPF. It is comprised of several components, including input data such as precipitation and potential evapotranspiration. If stream flow is influenced by snowmelt, additional meteorological data are necessary. To perform calculations with the Stanford Watershed Model, known or assumed initial conditions are incorporated into the model until the time series input data are exhausted. The model considers four storage zones for precipitation: upper-zone storage, lower-zone storage, groundwater, and snowpack. Overland flow, infiltration, interflow, base flow and flow-to-groundwater storage are routed within the upper and lower zones to the watershed outlet, where discharge can be expressed as a continuous out-flow hydrograph. To apply the Stanford Watershed Model, typically three to six years of rainfall-runoff data are necessary to calibrate the various parameters, and adjustments are made until an acceptable level of agreement between simulated and recorded flows is established.²

3 HYDROLOGY AND HABITAT OR CHANNEL DESIGN

Habitat and channel design is an integrated process requiring careful evaluation of hydrologic character – the timing, volume, and duration of flows. Hydrologic character in part determines channel and habitat characteristics. Hydrologic character must also be carefully considered with respect to public safety and infrastructure. The level of engineering and choice of structural and geotechnical materials is often based on the hydrologic regime, particularly when a project may affect public safety, infrastructure, aesthetics, economics and natural stream processes.

3.1 Flow Types

Distinct flow types and durations perform different geomorphic and biological functions, and have varying degrees of impact on human resources. The following flow types - low flow, dominant discharge, and flood flows - describe flow relative to stage (elevation of water surface within channel) and its relation to physical boundaries and conditions within the channel and floodplain environment:

3.1.1 Low Flow

Base flow conditions dominate the hydrograph of many streams, in terms of flow duration. A low-flow channel is often formed as an inset to the larger active channel. The low-flow channel may be broken

down into smaller segments with distinct geomorphic features such as riffles and pools. The stage in the low-flow channel is important to examine if the project's goals include specific revegetation and/or habitat requirements. For example, designing an adequate water depth and velocity is will be critical to fish survival. Likewise, the survival of riparian plant communities and other deep-rooted species and is an essential part of bioengineered treatments. Vegetation must be planted at the proper bank elevation to make use of soil moisture sustained during the growing season by base flows in the low-flow channel. The best, non-statistical approximation of the low flow discharge value in Washington is the ordinary high water mark, which is the flow that exists when the water-surface elevation is equal to the elevation of perennial vegetation. However, this will only be useful if the channel geometry and floodplain interactions are in equilibrium with the hydrologic regime. A discharge value, expressed in cubic feet per second (cfs), can be determined using Manning's equation¹ or by hydraulic analysis of a surveyed cross-section. (Manning's equation is explained later in this appendix under *Flow Resistance and Manning's Equation*, and in the *Hydraulics Appendix*.)

3.2 Dominant Discharge

Dominant discharge is the flow that produces the greatest morphologic effect over an extended period of time. Conceptually, dominant flow describes the flow type that controls the shape and function of the active channel. Consequently, dominant discharge should be used as the basis for design of natural channels. However, because dominant discharge is difficult to quantify, there are two alternative flows commonly used as substitutes:

- Effective discharge, the discharge that transports the most bed load. Effective discharge can be quantified with knowledge of the channel sediment budget and closely approximates dominant discharge. However, as sediment budget is difficult to quantify, effective discharge can be difficult to quantify.
- Bankfull flow. Bankfull flow occurs when the channel has reached its maximum capacity, and water surface is level with the floodplain. It generally approximates the dominant discharge only in comparatively undisturbed streams where flow patterns, sediment supply and channel geometry have been largely unaffected by human influences. In such relatively pristine streams, bankfull flow can be determined from measured cross sections using Manning's equation. Some channels, however, do not have distinct banks; thus, it is hard to determine floodplain-channel boundaries critical to defining bankfull conditions. In channels that are incised or are otherwise degraded, apparent bankfull flow may significantly exceed the dominant discharge and will, therefore, be inappropriate as a design discharge. (For a thorough discussion of bankfull discharge and its relation to channel geometry in the Pacific Northwest, refer to Castro and Jackson, 2001¹¹.)

(Comment: While dominant discharge is an interesting geomorphic concept, is it a useful tool for planning restoration projects? Effective discharge is extremely difficult to quantify (try measuring bedload transport sometime), and we probably shouldn't be implementing restoration projects in relatively pristine streams where bankfull flow is an approximation of dominant discharge.)

3.3 Flood Flow

Flood flows are those that exceed the capacity of the channel. Flood stage occurs when water overtops the channel banks. Incised channels, however, often have significantly more capacity than natural channels and may contain flood-level flows. Alternatively, in aggraded channels, flood flow may occur at greater frequency (lesser discharge) than in pre-existing conditions.

Flood flow values are commonly applied to channel design for protection of infrastructure or public safety and flood prevention. The 100-year flow is commonly used as a criterion for protection of infrastructure and for flood protection. For example, channel design projects may not be permitted if they affect the water surface elevation of the 100-year flood. 10-year, 50-year, and 100-year flows are common flood flows used in streambank designs. In un-gaged basins, various hydrologic models or regional regression equations may be used to derive flood flows.

3.4 Flow Resistance and Manning's Equation

Manning's equation quantifies the relationship between active channel geometry (i.e., width and depth of flow, slope, and roughness) and the average velocity of flow:

$$V = 1.49/n \cdot R^{2/3} \cdot s^{1/2} \quad (\text{English units})$$

Where V = average flow velocity,
 R = hydraulic radius (i.e., cross-sectional area of flow/average depth of flow),
 s = average channel slope (i.e., feet of drop/feet of horizontal channel length),
and n is a term expressing the roughness of the channel,

When designing a project component using Manning's equation, it is important to consider the relation of channel roughness to discharge. Roughness in a channel, represented by ' n ' in Manning's equation, integrates all those factors that create flow resistance, including bed substrate, bank vegetation and relative channel dimensions. Selection of a roughness coefficient, ' n ', will greatly affect the product of the equation. Manning's Equation is used to calculate discharge using the relationship:

$$Q = AV, \text{ where } A = \text{the cross-sectional area of flow.}$$

Roughness values (n) for stream channels can be approximated from reference sources such as those developed by H. H. Barnes, Jr.,¹² and D. M. Hicks and P. D. Mason.¹³

4 REFERENCES CITED

¹ Chow, V. T. 1959. Open Channel Hydraulics, McGraw-Hill, New York, NY.

² Chow, V. T., D. R. Maidment and L. W. Mays. 1988. Applied Hydrology: McGraw-Hill Series in Water Resources

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and Environmental Engineering. McGraw-Hill Book Company, New York, NY.

³ White, D.S. 1993. Perspectives on Defining and Delineating Hyporheic Zones. Journal of the North American Benthological Society. 12: 61-69.

⁴ Bolton, S. and J. Shellberg, 2001. White Paper: Ecological Issues in Floodplains and Riparian Corridors. WA Department of Fish and Wildlife, Olympia, WA.

⁵ Chow, V. T., D. R. Maidment and L. W. Mays. 1988. Applied Hydrology: McGraw-Hill Series in Water Resources and Environmental Engineering. McGraw-Hill Book Company, New York, NY.

⁶ Dunne, T. and L. B. Leopold. 1978. Water in Environmental Planning. W. H. Freeman and Company, New York, 818 pp

⁷ Ponce, V. M. 1988. Engineering Hydrology Principles and Practices. Prentice-Hall, Inc. Englewood Cliffs, NJ.

⁸ **U.S Army Corps of Engineers, 1998. HEC-1 Flood Hydrograph Package. Hydrologic Engineering Center. Davis, CA.**

⁹ **U.S Department of Agriculture, 1982. Project Formulation-Hydrology, Technical Release 20. Washington D.C**

¹⁰ **U.S Environmental Protection Agency, 1994. SWMM: Storm Water Management Model. Version 4.30. Office of Wetlands, Oceans, and Watersheds**

¹¹ Castro, J.M. and P.L. Jackson, 2001. Bankfull discharge recurrence intervals and regional hydraulic geometry relationships: Patterns in the Pacific Northwest, USA. Journal of the American Water Resources Association. Vol. 37, No. 5, pp. 1249-1262.

¹² **Barnes, H. H., Jr., 1967. Roughness Characteristics of Natural Channels. U.S. Geological Survey Water Supply Paper 1849.**

¹³ **Hicks, D. M. and P. D. Mason. 1998. Roughness Characteristics of New Zealand Rivers. National Institute of Water and Atmospheric Research, Ltd. Christchurch, New Zealand.**